Biological and Ecological Effects of Wastewater Discharges from Cruise Ships in Alaska

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Abstract- A Science Advisory Panel of the Alaska Cruise Ship Initiative investigated possible effects of commercial passenger vessel wastewater discharges on marine life in coastal waters of the Gulf of Alaska. The Panel concluded that due to the high dilution rates of moving cruise ships there is little likelihood of contaminant impacts to marine life in the water column, at the sea surface, in subsurface sediments or on the shoreline. However, stationary discharge in a low tidal exchange area could lead to water quality issues and should be minimized.

I. Introduction

Coastal waters of Alaska and the Pacific Northwest support a wide variety of marine life and marine resources of great value to all citizens of the United States. The public and their representatives are concerned that passenger vessel wastewater discharges may injure marine life and marine resources including life in open water (marine mammals, sea birds, fish and their eggs and larvae and the plankton), on the sea floor (bottom fish, crab, shrimp), and on shore (kelp and sea grass beds, shellfish, shorebirds, mammals).

In 1999 the State Legislature passed the Alaska Cruise Ship Initiative (ASCI) that established a Stakeholder Committee to evaluate the issues and recommend needed legislation. Sensing the need for a scientific evaluation, the Stakeholder Committee established a Science Advisory Panel (hereafter, the "Panel") to investigate specific issues and concerns with respect to the effects of commercial passenger vessel wastewater discharges on marine resources [1]. This paper summarizes the Panel's evaluation and understanding of the effects of passenger vessel wastewater discharges on marine life and marine resources. The paper is based on highlights from several sections of a November 2002 Panel report [2] submitted to the Alaska Department of Environmental Conservation (ADEC) and is a companion to several other papers in this conference volume dealing with passenger vessel wastewater sampling, chemistry, bacteriology and mixing rates. Space did not permit listing most of the dozens of references used; for a full bibliography, the reader is urged to consult the Panel report [2].

II. Background and Approach

Stakeholders were especially concerned about: (1) the toxicity of effluents to marine life, (2) the effects of nutrients and eutrophication, (3) effects on marine life at the sea surface, (4) chemical contamination of marine sediments, (5) environmental monitoring and, (6) criteria for identifying sensitive areas.

The Panel quickly determined that a risk-based approach would be useful in organizing our assessment. In this approach, expected environmental concentrations (EECs) of contaminants are estimated and compared to concentrations known to result in toxicity and bioaccumulation. Contaminants of concern to the Panel included conventional materials such as total suspended solids and nutrients (nitrogen, phosphorus) and trace chemicals, such as solvents, some pesticides and organo-chlorines, hydrocarbons, and trace metals. The State of Alaska has required sampling and analysis of contaminants in cruise ship and commercial passenger vessel wastewaters [3] thus providing an extensive database on chemical concentrations. Using data and information from existing literature, Panel oceanographers and previous reviewers [4] used models to estimate concentrations of

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contaminants in the wake of discharging passenger vessels [4]. Modeling results agreed well with dilution dye studies conducted by the EPA [4, 5]. The EPA dye dilution studies of discharging cruise ships resulted in dilutions ranging from 195,000 to over 600,000 parts seawater to 1 part effluent [5], somewhat greater (i.e., more diluted) than that simulated by the Panel models [4].

For purposes of estimating risks to marine life, Panel oceanographers recommended a conservative case be used for calculating expected water concentrations of contaminants: initial dilution rate of 50,000 to 1 for a large vessel discharging 200 m^3/hr at 6 knots [2]. Thus the highest concentrations of effluent or effluent constituents that marine life would be exposed to following discharge would be a maximum of 1/50,000th of the concentration of the material in the original (undiluted) effluent. For a moving passenger vessel, and in the absence of background contamination, a contaminant present in effluent at 1 part per million (1 ppm, or 1 mg/L) would be present in the wake at a concentration of 0.00002 ppm, or 0.02 parts per billion (ppb), or less, within 15 minutes following discharge. Out of the 55 priority pollutant categories sampled from large cruise ships, graywater and blackwater contained only 16 pollutants above detection limits (generally 1 ppb or less [2, 3]). Pesticides, PCBs, mercury and cadmium were not detected in the effluents. Ten organic chemicals (phthalates and several solvents) were detected in effluents at concentrations at or below 1 ppb (1 microgram per liter) while seven inorganic materials (6 metals and cyanide) were detected at mean concentrations on the order of 1 to 4 ppb [2, 3]. Upon discharge, and in the absence of background contamination, the concentrations of these chemicals in the wake of a ship would be on the order of parts per trillion. However, mean effluent concentrations of chlorine varied widely, from <0.3 to over 78 ppm, or 300 to 78,000 ppb. On discharge, chlorine could be at or above water quality criteria (2 ppb; see below).

These measured and modeled data set the stage for further evaluating the fate and effects of passenger vessel wastewater contaminants on marine life, as described below.

III. Wastewater Toxicity

Stakeholders wanted to know how toxic cruise ship wastewaters are to marine life. Panel modeling (above) suggested that wastewater contaminants would not be at concentrations toxic to marine life in the wake of a large cruise ship discharging wastewater while underway. Bioassays conducted in July 2002 by the Alaska Department of Environmental Conservation (ADEC) on a variety of commercial passenger vessel effluents, confirm this prediction and indicate that acute or chronic toxic effects on marine organisms are not expected at the high dilutions that occur when vessels are underway. The following summary is adapted from Appendix 8 of the Panel's report to ADEC [2].

Six different effluent samples from five different cruise ships operating in Alaska waters were analyzed for whole effluent toxicity (WET) in July 2002. Effluent samples covered a range of sources (black water or sewage from toilets, and gray water from sinks, showers and galleys), treatments and came from both large and small cruise ships. The sampling, transporting, and testing followed standard EPA methods, met all test acceptability criteria, fulfilled the requirements of the quality assurance (QA) plan and the testing was conducted in replicate by a WET-certified laboratory (AMEC, 2002). Observations of conventional water quality parameters were made upon receipt at ADEC's contract chemistry laboratory. Marine organisms used in the bioassays were exposed to a dilution series of six different concentrations of effluent. Because of the high initial dilution rates associated with moving cruise ships, the dilution series started at 50% effluent and was diluted further by a factor of 10 in each step such that the percent effluent tested progressively decreased. Testing included concentrations of 50%, 5%, 0.5%, 0.05%, 0.005% and 0.0005% effluent. The dilution series represented concentrations that are attained in receiving waters with dilution factors of 2, 20, 200, 2,000, 20,000 and 200,000, thus bracketing the 50,000:1 dilution recommended for risk evaluation.

Each effluent was tested using marine species likely to be sensitive to the effluents and that have well-established testing protocols. Two species were used for 48-hour static acute tests, where lethality was the effect measured: the mysiid shrimp, *Mysidopsis bahia*, and the fish topsmelt, *Atherinopsis affinis*. The samples were also tested for chronic or sub-lethal toxicity using (1) larvae of the mussel, *Mytilus galloprovincialis*, and (2) fertilization of gametes from the sea urchin, *Strongylocentrotus purpuratus*. Although these organisms are mainly native to the California coast, closely-related species live in Southeast Alaska waters.

Results are summarized in Table 1 in terms of No Observable Effects Concentrations (NOEC, or the highest concentration exhibiting no toxicity). Samples of blackwater (treated sewage) from *Vessesl B* and *E* did not demonstrate acute or chronic toxicity at any concentration. The mixed effluent sample from *Vessel C* demonstrated an effect at 50% (a dilution of one part seawater to one part wastewater, or 1:1) for the topsmelt acute and both chronic test species. Effluent samples from *Vessel A* and the *Vessel D* demonstrated some effect at 50% (1:1) concentration in the acute test and an effect at 5% wastewater concentration in the chronic tests. The *Vessel E* graywater sample exhibited the most observable toxicity effect of all effluents tested, requiring a dilution of 0.5 (2000:1) to reach NOEC level.

The greatest chronic toxicity measurement (Echinoderm fertilization, 1:2000) was observed in graywater from the small ship, *Vessel E*, which discharges continuously; attaining the necessary dilution might be a concern. The chronic toxicity of the *Vessel E* graywater and the *Vessel D* mixed effluent may be explained by the excessive chlorination of the effluent. Alaska's water quality standards for total residual chlorine are 2 ppb for salmonids and 10 ppb for other organisms. The total residual chlorine in the *Vessel E* graywater and *Vessel D* mixed effluent before dilution were 16,200 ppb and 30,300 ppb, respectively. These chlorine concentrations support the NOEC measured for these two vessels, where effects were observed at lower concentrations

Table 1: Whole Effluent Toxicity (WET) Test Results. Upper number is percent effluent, lower is effluent-to-seawater dilution ratio

No Observed Effect Concentration (NOEC) in % Effluent/Vessel	Treatment System	Mysiid Acute NOEC	Topsmelt Acute NOEC	Bivalve Larvae NOEC	Echinoderm Fertilization NOEC
Vessel A Graywater	Chlorine added to collection tanks	5 (1:20)	5 (1:20)	0.5 (1:200)	0.5 (1:200)
Vessel B Mixed Effluent	Reverse Osmosis	50 (1:2)	50 (1:2)	50 (>1:2)	50 (1:2)
Vessel C Mixed Effluent	Aerated Membrane (Ultrafiltration)	50 (1:2)	5 (1:20)	5 (1:20)	5 (1:20)
Vessel D Mixed Effluent	Macerator/ Chlorinator	5 (1:20)	5 (1:20)	5 (1:20)	0.5 (1:200)
Vessel E Graywater	Chlorine injection	0.5 (1:200)	0.5 (1:200)	0.5 (1:200)	0.05 (1:2000)
Vessel E Blackwater	Macerator/ Chlorinator	50 (>1:2)	50 (1:2)	50 (1:2)	50 (1:2)

than those of other vessels and effluents. The observed toxicity of the *Vessel A* graywater is not readily explained. There was no residual chlorine in the sample, but nevertheless, it would not be toxic at the dilutions estimated for cruise ships discharging while underway.

The lack of toxicity of the *Vessel E* blackwater sample (sewage) was also interesting. When the sample was drawn, it was evident that the treatment system was not functioning properly. However, the low bacteria concentration of 2,400 MPN/100 ml indicates that the effluent must have been chlorinated, but not with enough chlorine to leave any residual chlorine at the time of the test. For all four tests, the sample exhibited no acute or chronic toxicity at the highest concentration (50%).

Regardless of the NOEC variations and ranges, all of the NOEC dilutions are considerably lower that the nominal dilution of 50,000:1 achieved by a large twin-screw vessel discharging 200 m^3/hour while traveling at six knots. The various effluents tested and analyzed would be expected to impart no acute or chronic toxic effects to marine organisms at the high dilutions that occur when vessels are underway. However, the highly chlorinated graywater effluent from a continually-discharging small cruise ship could be a concern if the effluent was discharged when moored, drifting or at anchor because dilution benefits are greatly reduced at such times. The effluents from the vessel employing reverse osmosis advanced treatment technology (*Vessel B)* would not be expected to impart observable effects on marine organisms if discharged in port. The effluents from the vessel employing ultrafiltration advanced treatment technology (*Vessel C*) would not be expected to impart observable effects on marine organisms if discharged in port, provided the effluent is diluted by a factor 20. The Panel believes this mixing rate is easily achieved for large cruise ships, given the discharge velocity required to overcome the static head pressure at the depth of the discharge port. Finally, this limited but detailed study highlighted the trade-offs created when chlorine is used for disinfection. WET testing will continue.

IV. Effects of Nutrients

Stakeholders wanted to know if nutrients discharged from cruise ships would stimulate phytoplankton blooms or cause eutrophication in nearshore coastal waters. Analysis of concentrations of nutrients in passenger vessel wastewaters in 2000 through 2002, nutrient dilution rates in the wake of moving passenger vessels, and data on background nutrient conditions and the cycle of phytoplankton blooms in Southeast Alaska, lead the Panel to conclude that the discharges of wastewater do not significantly contribute to stimulating phytoplankton blooms or eutrophication in this region. The following summary is adapted from Section 4 of the Panel's report to ADEC [2].

The growth of phytoplankton in coastal marine waters of Alaska is dependent on, and limited by, light and by concentrations of nutrients, mainly nitrogen (nitrate, nitrite and ammonia) but to some extent phosphate and silicate. Inorganic compounds of nitrogen and phosphorus are normal constituents in coastal seawater. Concentrations of these nutrients in upper (20m) nearshore coastal surface waters of the Alaskan coast undergo large annual cycles, with the highest concentrations (near 40 uM [micro-molar] as nitrite plus nitrate) occurring in winter, when available sun light is extremely low, and the lowest concentrations in summer [6]. In the spring (March to May) when sun light is increasing, phytoplankton in the upper part of the water grow and multiply rapidly, consuming the previous winter's load of nitrogen and phosphate. By mid-summer (June, July) phytoplankton blooms have consumed much of the available nutrient load and have themselves decreased in concentration due to the nutrient limitations and predation by zooplankton. It is this period of great transition (spring), followed by low surface water nutrient concentrations (summer), that passenger vessel traffic, and the need to discharge wastewater, is most intense.

Nutrients were measured in passenger vessel wastewaters during the summers of 2000 thru 2002 [2, 3]. The statistical means for the total nitrogen content of graywater, which is

the significant majority volume of the cruise ship wastewater discharged to the ocean, lie between about 20 to 100 mg/l (1.5 to 5 millimolar, mM, or 1500 to 5000 micro-molar, uM) depending on different sub-sets of the data (converted from data in [2]). A few samples had high concentrations, resulting in a higher mean. Untreated black water had means of about 300 to 400 mg/l (20 to 30 mM). For the purposes of our evaluation, the Panel conservatively estimates that discharged water can have a total nitrogen concentration up to 5 mM (the upper limit of the mean).

An initial dilution factor of 50,000 in the near field for a moving ship gives concentrations of (5mM/50,000 =) 0.1 µM total nitrogen. In spring, the concentration of nitrate plus nitrite in surface water starts at 30 µM, nearly 300 times higher than 0.1 µM and decreases toward 1 µM during late summer and early fall, still at least 10 times higher than the diluted discharge. It is evident from these estimates that the discharged water will have little impact on the natural nutrient cycle, including during summer, the most nutrient-sensitive period.

This amount of nitrogen can be converted to a very small amount of phytoplankton over the next several days, approximately 0.03 micrograms of chlorophyll per liter. This amount of chlorophyll is equivalent to only a hundredth to a thousandth of the standing crop of phytoplankton. Thus the amount of nitrogen discharged by passenger vessels would not be expected to result in a phytoplankton bloom in the wake of a cruise ship wastewater discharge. To experience such a bloom, the surface water would have to receive 10 to 100 times as much nitrogen.

Table 2. Concentrations of nitrogen in wastewaters, wake water and background seawater

Medium	Nitrogen (uM)
Blackwater	20,000 - 30,000
Graywater	1,500 - 5, 000
Diluted Blackwater	0.4 to 0.6
Diluted Graywater	0.03 to 0.01
SE Alaska nearshore water	
Winter	20 - 40
Summer	0 - 2

However, small passenger ships, which are allowed to discharge while moored or at anchor in coves and bays, may have some limited potential to promote phytoplankton blooms in poorly flushed coves, bays and inlets. Small-fleet discharges represent only 2.5% of the total cruise ship wastewater discharge into Alaska waters [1]. A small ship will typically discharge 1 m^3/hr whereas a large cruise ship may discharge at 200 m^3/hr. Thus, the nutrient impact of small ships, even during stationary discharge, is likely to be small. However, repeated discharges by small ships into a small embayment could create a significant phytoplankton bloom if water exchange within the bay is minimal.

Large cruise ships employing advanced treatment technology could be allowed to discharge in port or at anchor provided they meet effluent criteria for fecal coliform, suspended solids, biochemical oxygen demand and pH. Advanced technologies may reduce nutrient concentrations in the wastewater discharge. This assumption should be validated through continued sampling and analysis in subsequent years.

V. Effects on the Sea Surface Microlayer

Stakeholders wanted to know to what extent chemicals from cruise ship wastewater discharges would contaminate the sea surface microlayer. Analysis of concentrations of chemical contaminant concentrations in passenger vessel wastewaters in 2000 through 2001, coupled with contaminant dilution rates in the wake of moving passenger vessels, and an understanding of microlayer formation, lead the Panel to conclude that the discharges of wastewater should not measurably contaminate the sea surface microlayer in nearshore Alaska waters. A field study would be helpful to confirm this conclusion. The following summary is adapted from Section 6 of the Panel's report to ADEC [2], which includes an extensive literature review.

The surface water microlayer or sea surface film is a complex air-seawater interface 200-300 microns (uM) thick containing organic and inorganic material and accumulations of life forms, often at concentrations significantly elevated from that of the waters beneath the film. This microlayer is most visible in calm weather as a sheen on the sea surface, especially in quiet coves and bays. The microlayer includes lipids, proteins, polysaccharides and humic substances on the order of 0.1 uM thick followed by a bacterioneuston layer up to 1.0 uM in thickness [7]. Other more complex organisms use the surface tension of this microlayer during different stages of development (e.g., egg adhesion, larval attachment). The higher levels of particulates and natural compounds in the sea surface microlayer can sequester or absorb trace metals and organic contaminants. The microlayer is also a dynamic environment, affected by wind stress, evaporation, solar energy flux, ultraviolet energy absorption and inputs of material from the atmosphere. The microlayer is disrupted by physical action such as from waves and passing ships, but reforms quickly in calm conditions. The passage of a vessel's propellers and hull is disruptive to the microlayer and probably causes some unknown quantity of plankton and fish larval mortality [8].

The Panel investigated the possibility that contaminants from large cruise ship wastewater discharge might adversely impact marine life at the sea surface. With the higher levels of particulates and natural compounds (carbohydrates, proteins and lipids) in the sea surface microlayer, it is obvious that this interface should provide a favorable environment for contaminants to accumulate since they can adsorb to particulate surfaces or co-solublize or sequester with some of the natural compounds that accumulate at this interface.

The literature on trace metals and organic contaminants that accumulate at this interface has been presented by Maki

[7] and reviewed in detail by the Panel [2]. Our review indicated the following:

(1) There appear to be no recent published studies of the sea surface microlayer and none have been done specifically in Alaska. Most of the coastal marine studies on microlayer contamination were conducted 15 to 20 years ago in Southern California [11], Puget Sound [10] and Narragansett Bay, Rhode Island [9].

(2) Sub-surface waters, even in urban areas, contain extremely low concentrations of metals and organic contaminants, often in the parts per billion (ppb or ug/L) range and lower. By contrast, concentrations of contaminant, especially organic chemicals, in the surface microlayer from urban areas have been ten, a hundred or even a thousand times higher than in subsurface water immediately below the microlayer. For example, surface-to-subsurface enrichment ratios in the range of 1.4 to > 9 for a range of metals and organic contaminants [9]. Concentrations of metals and organic contaminants in the range of tens to over 8000 ppb in samples of surface water microlayer were reported from various areas in Puget Sound [10]. Based on our understanding of bulk sea water chemistry in Puget we estimate that enrichment ratios at the most contaminated site in Elliot Bay, near Seattle, were on the order of 600 for metals and 1100 for polycyclic aromatic hydrocarbons (PAHs).

(4) Surface microlayer contamination increases with proximity to urban areas. For example, off Los Angeles, total metals in surface microlayer increased from 10 ug/L 15 km offshore to concentrations ranging from 1173 to 12168 ug/L at sites in Los Angeles Harbor [11] or 100 to 1000-fold; in the same samples, total polycyclic aromatic hydrocarbons (PAHs) increased by as much as 1500 times, from 35 nanograms per liter (parts per trillion) offshore to as high as 55,775 ng/L in Los Angeles Harbor. Similar gradients were reported for Puget Sound and the Straits of Juan de Fuca [10].

(5) When the microlayer becomes highly contaminated with chemicals, it also becomes more toxic. In laboratory toxicity tests, [10] found that compared to reference sites, the surface microlayer from urban bay sites in Puget Sound generally resulted in more chromosomal aberrations in developing sole larvae, reduced hatching success of sole larvae, and reduced growth of trout cell cultures. In situ hatching success of sole eggs was reduced by half or more in urban bays compared to reference sites. The Puget Sound studies are supported by other research in California [11] where larval mortality and chromosomal aberrations were greater in kelp bass in exposed to microlayer samples from harbor areas compared to those offshore. The toxicity correlated well with the contaminant levels (total metals and PAHs) in the surface layer collected by Teflon and ceramic drums.

Thus the extent to which the microlayer will become contaminated by chemicals from wastewaters, discharged and mixed below the surface, depends on several competing processes: (1) initial dilution and mixing and (2) reformation of the microlayer and surfacing of some of the discharged contaminants. At an initial dilution of 50,000:1 or greater the only contaminant likely to be measured above ambient levels in bulk seawater would be fecal coliforms [12]. However, as reviewed above, evidence indicates that there is the potential for the microlayer to concentrate some contaminants 10 to 100 times or more above the ambient concentrations. There is the added complexity with the discharge of very hydrophobic substances such as oil and grease from galleys since these substances would naturally rise to the surface and tend to concentrate there unless they were adequately dispersed or emulsified by the discharge and mixing processes. To determine the actual magnitude of the interface concentration process in an area where large numbers of cruise ships pass regularly would take a very carefully designed study with great care taken on the selection of reference or control sites.

The Panel concluded that, in the absence of vessel-specific microlayer investigation, the high dilution of wastewater caused by a large moving cruise ship should prevent significant accumulation of contaminants in the microlayer, even after accounting for the sequestering or enrichment properties of the microlayer. This conclusion is further bolstered by the Whole Effluent Toxicity (WET) tests conducted in July 2002 (see above). Small cruise ships that discharge small amounts of wastewater while anchored or stationary in fjords and embayment may have some limited potential for adverse impact to the fresh water layers found in fjords and embayments.

VI. Sediment Contamination

Stakeholders wanted to know to what extent bottom sediments underneath cruise ship tracklines would likely be contaminated by chemicals from cruise ship wastewater discharges. Contaminated sediments can injure benthic marine life. Analysis of chemical contaminant concentrations in passenger vessel wastewaters in 2000 through 2001 coupled with known contaminant dilution rates in the wake of moving passenger vessels, and assumptions about the binding and settling of contaminants on wastewater particles, led the Panel to conclude that the discharges of wastewater will not measurably contaminate the bottom sediments in nearshore Alaska waters. The following summary is adapted from Section 5 of the Panel's report to ADEC [2].

Many contaminants are relatively insoluble in seawater and tend to adsorb to particles in the wastewater effluent and in the receiving environment. These particulate-bound contaminants can settle and accumulate in the bed sediments and can often present a chronological record of contamination in an area around point sources such as wastewater outfalls. Bioturbation (the disruption of sediment by organisms, e.g., by churning or burrowing) can mix sediments and diagenetic (e.g., compaction, dissolution and cementation) processes can redistribute contaminants in the sediment profile. Fortunately, we know more about the transport of water-borne contaminants to the sea floor than we do about their transport to the surface.

To put the discharges of cruise ships into perspective in terms of sediment contamination, calculations can be done to determine the level of contaminants that could be associated with the solids discharged from a ship and compared to those levels in published sediment quality guidelines. Total suspended solids (TSS) data collected from cruise ships (large and small) during the 2001 season show a large range of TSS concentrations but an overall assessment of these data show that median or geometric mean values of TSS are less than 150 mg/L. 150 mg/L TSS is a conservative value for calculation purposes. This is also the permitted discharge limit set by the State of Alaska so it will represent the maximum TSS values in the future and not the median as more vessels come into compliance. Using trace metals as an example and assuming that 75 % of the measured trace metals are associated with the particulate fraction of the wastewater, one can calculate a possible metal concentration in the solid fraction of the wastewater and compare the calculated concentrations to various sediment quality criteria Table 3).

The calculations (Table 3) show that the TSS particles in the effluent can exceed various sediment criteria for As, Cu and Zn. However, as these solids leave the ship and undergo turbulent mixing from the vessel's passage, the particles are spread over an area comparable to the width of the wake turbulence (e.g., 100 m) very quickly (less than 15 minutes) and at a minimum dilution of 50,000 to 1. The smaller particles will take days to settle to the bottom, if they settle at all, and larger particles will sink more quickly. Many particles consist of organic matter and some of those particles will be consumed by bacteria and zooplankton before they can settle. As these particles slowly sink through the water column, they will be further dispersed by tidal currents, eddies and turbulent mixing. The longer the particles are suspended in the water column, the farther from the point of entry they are likely to travel before they can settle on the bottom, and thus the more spread out they are.

Table 3: Estimate of Trace Metals Associated with Solids from Cruise Ships

Trace Metal	Concentration Liquid ug/L	Solid mg/kg	Sediment Quality Guideline ISQC	PEL	AET
As	9.20	46	7.24	41.6	57
Cr	3.42	17.1	52.3	160	260
Cu	82.9	414	18.7	108	390
Pb	2.96	14.8	30.2	112	450
Zn	130	653	124	271	410

(1) Metal effluent concentrations represent a geometric mean from three data sets, namely large cruise ships gray water (2001), large cruise ships black water (2001) [3 and small cruise ships (2002).

(2) Concentration in solids are based on a value of 150 mg/L TSS and assuming that 75% of the total metal is associated with the particulate phase in the wastewater.

(3) CCME (2001) [13] interim sediment quality criteria (ISQC) and probable effects level (PEL) for marine sediments.

(4) WAC 173-204-320. Washington State sediment quality standards based on apparent effects threshold (AET).

In addition to dispersion in the ship's wake, sediment transport from high sediment sources such as large rivers, e.g., Fraser, Skeena, Stikine, as well as high sediment loads from melting glaciers (e.g., Taku, Mendenhall) will effectively combine with the particle associated contaminants from cruise ship discharges and reduce their concentration in the bottom sediments. Natural sediment deposition rates in passages of Southeast Alaska have been measured and are very high. In Lynn Canal, measured deposition rates varied from 1.88 g/day at a depth of 60 m to 38.8 g/day/ m2 at a depth of nearly 300 m (reviewed in [2]). These are comparable to rates in Puget Sound 8.2 and 32.9 g/day/m2) and both are considerably higher than in the Southern California Bight (0.3 g/day/m2, reviewed in [2]).

To our knowledge, no one has yet measured the flux of contaminants to the sea floor from discharging vessels other than sludge barges. Cruise ships do not discharge sludges nearshore. Therefore, the Panel developed its own scenarios to evaluate the potential for a pollutant from cruise ship wastewater discharges to enter and contaminate the sediments in SE Alaska coastal areas. The Panel selected copper as the contaminant with the most potential to be a problem based on the wastewater priority pollutant data from cruise ships monitored in 2001 and 2002. The scenarios required developing a contaminant (copper) loading rate as follows: (1) identify a realistic average concentration of copper in effluents, (2) assume that a percentage (75%) of that copper binds to suspended solids in the effluent, (3) assume a mass of copper delivered by a reasonable number of cruise ships to an area over a year, (4) assume an area over which the copper may settle, calculating a rate in milligrams per year per square meter, and (5) compare this settling rate to a reasonably conservative estimate of the rate of natural sedimentation. This process leads to a steady-state estimate of excess copper concentrations in marine surface sediments underneath ship tracklines (paths). The concentrations so determined are then compared to various sediment quality guideline derived by various states and agencies.

We first calculated the expected copper flux per linear meter of ship trackline. A large cruise ship discharges a graywater/treated blackwater mix at 200 m^3/hr at a minimum speed of 6 knots (about 11,000 m/hr) at least one nautical mile (about 1850 m) from the nearest shore. In one hour, the ship travels 11,000 m. Assuming an average suspended solid concentration in the wastewater effluent is 150 mg/l with 75% of the 82.9 ug/l copper bound, the amount (mass) of copper discharged in one hour is 12,450 mg or about 12.5 grams (less than half an ounce). The amount of copper discharged per meter that the ship travels is 1.13 mg Cu/m.

We next assumed that three vessels travel exactly the same trackline each day during the cruise ship season (about 150 days). For this calculation we are assuming that accuracy in following another ship's track is within 100 m, a very unlikely event. The amount of copper discharged per meter from three ships over a cruise season of 150 days is 509 mg Cu/m ship-track/year.

We then applied this basic loading rate to each of three scenarios: (1) the copper is rapidly mixed in the water out to

a width of 100 m perpendicular to the track, but then does not spread any further and eventually settles to the bottom along a 100 m swath; (2) the copper is deposited in a 100 m swath, but the ship tracks are adjacent, i.e., not the same track, yielded an effective swath width of 300, and; (3) the copper binds to very small particles that will be spread over a much wider area and in the case of a channel area 2 nautical miles (3.5 km) wide, would settle along a 3,500 m swath. As seen in Table 4, the amount of copper added to each square meter of sediment surface per year under these assumptions is:

Table 4: Estimate of Copper Deposition and Sediment Concentration Associated with Solids from Cruise Ships

(1) Scenario width (m)	(2) Swath (mg/y/m^2)	(3) Flux (mg/kg: ppm dw)	(4) Expected Sediment Concentration ppm
1	100	5.1	2.9
2	300	1.7	0.9
3	3500	0.15	0.08

Thus, from column 2, above, if the ship tracks shift by 100 m (i.e., a 300 m wide swath results from the 3 ships), the amount of copper/m^2 added annually to the sediments drops by a factor of 3 (from 5.1 to 1.7 mg/y/m^2). Letting the copper drift a mile to either side of the main ship track decreases the copper/m^2 added to the sediments by more than a factor of 10 (from 1.7 to 0.15 mg/y/m^2).

To the above numbers we now determine copper concentrations in sediments by factoring in the rate of natural sedimentation. As noted above, suspended sediment trap studies and analysis of sedimentation rates from cores in Southeast Alaska have identified sedimentation rates varying from 1.88 gm/day/m^2 to 41 gm/day/m^2 (reviewed in [2]). Sedimentation rates are greatest for deeper waters. Even in Puget Sound, Washington, sedimentation rates below 150 meters vary from 8 to 33 g/day/m^2. The available data suggest that a natural sedimentation rate of 5 g/day/m^2 would serve as a conservative low estimate for this analysis. Using the low rate of sedimentation of 5 g/day/m^2 the annual sediment solids flux rate is 1825 g/year/m^2. Dividing the ship wastewater copper flux by the natural sedimentation flux gives sediment concentrations in mg/kg dw or ppm. As shown in Table 4, Column 4, these values are 2.9 ppm (mg/kg dw) for scenario 1, 0.9 ppm for scenario 2, and 0.08 ppm for scenario 3.

These concentrations may be compared to existing guidelines, such as NOAA's Screening Quick Reference Tables (SQRTs: http://reponse.restoration.noaa.gov) and identifies a range of marine sediment guidelines for copper:

18.7 mg/kg = Threshold Effects Level (TEL, Canada)
34 mg/kg = Effects Range-Low (ERL)
108.2 mg/kg = Probable Effects Level (PEL)
270 mg/kg = Effects Range Median (ERM)
390 mg/kg = Apparent Effects Threshold (AET, Washington)

These expected concentrations from the nominal cruise ship discharges, (0.08 to 2.9 ppm), as calculated above, are well below sediment copper guidelines and criteria (range from 18.7 to 390 mg/kg dw (ppm) and therefore would not be expected to affect bottom marine organisms.

The calculated copper concentrations must also be evaluated in the context of the natural background levels of copper in marine sediments in SE Alaska which are typically in the 30 to 40+ ppm range (reviewed in [2]). These naturally occurring copper sediment concentrations in Alaskan sediments actually exceed the two lowest guidelines, bringing into question the relevance of those guidelines to Alaska.

In summary, copper discharged in cruise ship discharges under reasonable worst-case loading scenarios, is not expected to contaminate sediments to the extent of affecting benthic marine organisms. Elsewhere in the United States and Canada contaminated sediments are usually adjacent to industrialized waterways or areas with historic inputs from stationary, continuous point source discharges, and discharges of storm water or combined sewer overflows. The characteristic of such discharges is that they have much less dilution than do large cruise ships.

We did not make similar calculations for organic chemicals either because they were not detected in the cruise ship wastewaters (such as PCBs) or because they are not known to appreciably bind to sediments (such as the volatile organics and solvents).

The above analysis is a conservative one in all three cases. Cruise ships often travel faster than 6 knots and often discharge at a lower rate than 200 m^3/hr. The assumption of three ships a day for 150 days is a greater release rate than actually occurs for most Southeast Alaska waters, but might be a feasible release rate for some limited areas. In truth, the fine suspended solids discharged from the ship will fall slowly to the bottom while mixing with eddies, and washing back and forth with the tides. This slow rain of highly-dispersed particles will spread away from the discharge point in all directions. Individual particles could fall near the ship track, miles away from the ship track or not sink at all. The Panel considers that all the above estimates of added copper/m^2 are likely to overestimate the real situation by factors of 10. In deeper areas (where more sediments collect) individual particles will take longer to sink to the bottom, and thus may be carried farther away. Also, in shallower open areas (where fewer fine sediments collect) such as sills where the particles have a shorter travel to the bottom, the currents are likely to be stronger, again allowing the particles to travel farther before coming to rest on the bottom. Thus, the Panel concludes that our estimates of the increases in copper concentration in bottom sediments attributable to cruise ship discharges are very high compared to what actually happens.

It should be noted here that since mass is conserved, the transport and transformation of the pollutants must eventually consider all processes together (solution or suspension in the water column, settling to the sea floor, rising into the microlayer): when one is increased the others must decrease. For example, if 75% of a metal is bound to particulates and

settle, only 25% remains to be either suspended or dissolved in the water column or to rise to the surface and become incorporated into the surface micro-layer. Our ability to assign a "budget" for the contaminants is limited to modeling until such time that a detailed chemical fate study, if justified, can be done. It is not clear that such a study is needed at this time.

VII. Environmental Monitoring: Using "Mussel Watch"

Stakeholders needed to know to what has been done to monitor environmental contamination from cruise ship discharges and what to do in the future. There has been no monitoring of Alaskan coastal waters, sediments or marine life directed at documenting what effect, if any, cruise ship wastewater discharges have on marine water and sediment quality or on marine resources. However, analysis of concentrations of chemical contaminant concentrations in mussels (*Mytilus trosselus*) at several locations along passenger vessel routes led the Panel to conclude that the discharges of wastewater have not lead to increased chemical contamination. These analyses also show that there is a low background of chemical contamination along the Alaskan coast due most probably to global atmospheric transport and fallout. The following summary is adapted from Section 10 of the Panel's report to ADEC [2].

Contaminant monitoring surveys along the Gulf of Alaska coast include the NOAA National Status and Trends (NS&T) Program and the Prince William Sound Regional Citizens Advisory Council (RCAC) Long Term Monitoring Program. From 1984 to 1990 the NOAA NS&T Program analyzed contaminants in sediments and bottom fish at several Alaska sites as part of a nation-wide "Benthic Surveillance" program conducted by NOAA Fisheries in Seattle. In 1986, the NOAA NS&T Program began measuring contaminants in inter-tidal mussels, and adjacent sediments, at several Alaska sites as part of the National "Mussel Watch" (MW) Program [14]. Mussels readily concentrate (bioaccumulate) in their tissues many non-volatile organic compounds and trace metals. The Mussel Watch chemical list includes PCBs, organochlorine pesticides (such as DDTs), polycyclic aromatic hydrocarbons (PAH's) and a suite of 14 trace metals (such as lead, Pb, copper, Cu, and mercury, Hg, Table 5). The five sites Mountain Point near Ketchikan, Nahku Bay adjacent to Skagway, Mineral Creek Flats east of Valdez, Siwash Bay at Unakwik Inlet in northern Prince William Sound, and Homer Spit in Cook Inlet, all near high vessel traffic areas. Sampling at the Valdez and Unakwik sites began in 1986 whereas sampling at the other three did not begin until 1993. Sampling is annually or biennial, in the spring. Whole soft tissues from 30-50 mussels are composited, chemically analyzed and results reported in ppb or ppm dry weight (dw). If vessels are discharging sufficient amounts of contaminants near these areas prior to sampling their contributions to contaminants could be measurable. But, the sampling does occur before the cruise ship season. The most recent sampling was in spring, 2001.

Nearly all organic contaminants measured in the NS&T Mussel Watch program have been found at low concentrations in these Alaska mussels (Table 5).

Table 5: Contaminant concentrations in mussels from 5 Alaska sites sampled in spring, 2001 as part of the NOAA National Status and Trends Program. Units are ppb (ug/kg) dw for organic chemicals and ppm (mg/kg) dw for metals.

ANALYTE	**Alaska**	N=5		West	N=52		**West/AK**
	Mean	Min	Max	**Mean**	Min	Max	**Ratio**
% Dry weight	**14**	12	17	**16**	8	22	**1.1**
% Moisture	**86**	83	88	**84**	78	92	**1.0**
PAH's (total of 44)	**89**	52	144	**1982**	35	46698	**22.4**
FFPI	**0.56**	0.45	0.68	**0.45**	0.16	0.88	**0.8**
Total PCB	**13.06**	7.81	24.2	**148.7**	7.46	1429.4	**11.4**
Total DDT	**1.52**	0.89	3.27	**64.9**	2.01	491.5	**42.7**
Total Chlordane	**1.39**	0.89	3.03	**15.9**	1.51	148.6	**11.4**
Hexachlorohexanes	**2.03**	1.16	2.47	**2.54**	0.29	8.67	**1.3**
Chlorpyrifos	**0.40**	0.00	0.73	**0.39**	0.00	3.78	**1.0**
Aldrin	**0.00**	0.00	0.00	**0.03**	0.00	1.66	**a**
Dieldrin	**0.44**	0.23	0.85	**7.32**	0.42	183.8	**16.8**
Endrin	**0.02**	0.00	0.12	**0.54**	0.00	8.98	**22.2**
1,2,3,4-TCB	**0.09**	0.00	0.30	**0.04**	0.00	0.52	**0.4**
1,2,4,5-TCB	**0.00**	0.00	0.00	**0.15**	0.00	3.21	**a**
HCB	**0.60**	0.48	0.97	**0.64**	0.00	10.9	**1.1**
Pentachloroanisole	**0.24**	0.20	0.29	**1.34**	0.30	4.13	**5.6**
Pentachlorobenzen	**0.08**	0.00	0.12	**0.24**	0.00	2.02	**3.1**
Endosulfan II	**0.13**	0.08	0.24	**1.16**	0.00	18.3	**9.2**
Endosulfan I	**0.00**	0.00	0.00	**1.50**	0.00	18.5	**a**
Endosulfan Sulfate	**0.00**	0.00	0.00	**0.17**	0.00	2.81	**a**
Mirex	**0.00**	0.00	0.00	**0.07**	0.00	0.77	**a**
Tributyltin (TBT)	**4.97**	2.78	7.43	**24.8**	0.00	189	**5.0**
Total Butyltins	**9.5**	2.8	19.8	**36.7**	0.00	278	**3.9**
Silver (Ag)	**0.7**	0.15	1.70	**1.01**	0.03	6.48	**1.4**
Aluminum (Al)	**644**	62	1149	**506**	29	1668	**0.8**
Arsenic (As)	**13.6**	12.0	15.0	**11.6**	5.9	30.8	**0.9**
Cadmium (Cd)	**4.33**	1.95	6.28	**4.24**	0.43	15.6	**1.0**
Chromium (Cr)	**2.08**	0.38	6.01	**3.10**	1.07	11.8	**1.5**
Copper (Cu)	**8.41**	7.17	10.75	**9.10**	3.64	15.8	**1.1**
Iron (Fe)	**762**	151	1368	**679**	55	2305	**0.9**
Mercury (Hg)	**0.110**	0.08	0.15	**0.14**	0.03	0.50	**1.2**
Manganese (Mn)	**20.9**	9.4	28.1	**23.9**	4.4	146	**1.1**
Nickel (Ni)	**3.93**	1.51	7.03	**2.69**	0.25	8.65	**0.7**
Lead (Pb)	**1.04**	0.37	1.78	**1.43**	0.14	7.28	**1.4**
Selenium (Se)	**5.30**	3.7	8.1	**4.3**	2.1	10.6	**0.8**
Tin (Sn)	**0.279**	0.003	0.993	**0.274**	0.00	1.66	**1.0**
Zinc (Zn)	**82**	48	111	**168**	70	309	**2.1**

For most organic chemicals, concentrations in mussels from these sites were much lower than in mussels sampled elsewhere along the U.S. West Coast (California, Oregon and

Washington) inn 2000 and 2001 (Table 5). Organic contaminants with the highest concentrations in the Alaskan mussels included total Polycyclic Aromatic Hydrocarbons (PAH's, the sum of 44 compounds, mean 89 ppb dw, range 52 to 144) and total PCB's (mean 13 ppb dw, range 7.8 to 24.2). The average concentrations of these chemicals in mussels from 52 other sites along the US West Coast are over 20 and 10 times higher, respectively (Table 5). Concentrations of the pesticide DDT were over 40 times higher along the West Coast (mean 492 ppb dw) than at these Alaska sites (mean 1.5 ppb dw, Table 5). Mean concentrations of all other organochlorine compounds, other than hexachlorohexanes, were below 1 ppb in Alaskan mussels, but ranged as high as 184 ppb dw for dieldrin in West Coast mussels. However, concentrations of several organochlorines, namely lindane-related compounds (hexachlorohexanes), hexachlorobenzene, and the pesticide chlorpyrifos, were equal to or higher in mussels from Alaska than in those from farther south along the U.S. West Coast. These low levels are probably due to the precipitation and snowmelt runoff of these compounds from global atmospheric sources. However, one of them, chlorpyrifos, may have been used in past years aboard ships as well as around shore-based facilities.

Butyltins, compounds that still may be used in anti-fouling paints on large vessels, were present in mussels from all five Alaska sites, but at concentrations two to five times lower than the average for the US West Coast (Table 5). Concentrations of all other trace metals, including cadmium, mercury and lead, were comparable between the Alaska sites and the sites from the rest of the US West Coast. A half dozen metals were higher in mussels from the least "urbanized" site, Unakwik Inlet, than from the more urbanized sites (Skagway, Ketchikan, Valdez, Homer; data not shown, see Panel report [2]).

There are few consistent longterm trends of chemical contamination in mussels from these Alaska sites. The metal lead (Pb) has been elevated in mussels from the site at Skagway, but is now approximating concentrations found elsewhere in Alaska. With the possible exception of mercury, there have been no longterm increases in contamination but some, such as PCB's and PAH's, have been decreasing in concentrations during the past decade or more; the slight increase in mercury is most notable at the least urbanized site (Unakwik Inlet).

None of the contaminant concentrations found in Alaska mussels exceed or approach seafood consumption guidelines. See Section 10 of the Panel report to ADEC [1] for more details.

Other data sources indicate that PAH's in mussels from marinas and boat harbors in Prince William Sound are as high or higher than in mussels from the West Coast urban bays.

Time and resources did not allow for analysis of data on contaminants in sediments or fish from these and other sites nor have we completed a review of historical data on contaminants in commercial fishes of Alaska from large-scale surveys conducted during the late 1960s through the 1970's.

Obviously, more data from Alaska coastal sites are needed, at the right time (summer), to determine if passenger vessel activity is a relevant contributor to coastal contamination, for example in remote tourist destinations such as Glacier Bay and Tracey Arm. Environmental monitoring provides a check that regulatory actions have their intended benefit and reduces uncertainty that there are no surprises. Although it is important to note that the Panel believes cruise ships are not likely to contribute measurable contamination, an enhanced monitoring of contaminants in mussels and sediments in Southeast Alaska, Prince William Sound, along the Kenai Peninsula, and in Cook Inlet, during the tourist season, could provide a valuable tool in assuring that state coastal waters remain relatively uncontaminated.

VIII. Sensitive Areas/ Cumulative Effects

Stakeholders wanted to know: are there waters and nearby shorelines that might be more sensitive than other areas to cruise ship discharges? So much more sensitive that discharging should be restricted? The Panel offered several guidelines

Two approaches need to be considered: sensitive areas and sensitive species. A *sensitive area* with respect to wastewater discharge is simply any area where concentrations of contaminants are likely to exceed water, sediment or seafood quality criteria, guidelines or public expectations. A *sensitive species* is either: (a) sensitive to wastewater (finding wastewater toxic), or (b) one that humans or predators consume and find toxic because they have been exposed to wastewater. Factors to consider include: location, oceanography, species and time of year or day.

The premise is that we can define locations in both time and space where discharges may cause a high enough exposure potential (concentration multiplied by time) for harm that action should be taken. Time must be considered because the pollutants do not affect the water itself. Rather, it is the living things that live in the water and the animals further up the food web that depend on those local resources that are potentially affected. The degree of impact depends on what a particular organism is exposed to, for how long, and at what dose. Both the water and resources are potentially moving through a particular area at particular times, which limits and complicates contaminant exposure.

The simplest consideration is of resources that are of interest to humans and that do not change locations – confined or sessile species that are planned for human use and consumption. Fish pens and harvested shellfish beds fall into this category. Shellfish and other sessile or confined consumable bioaccumulators need to be protected from repeated contact with contaminants.

Other animals may have life stages that are particularly sensitive to contact with certain contaminants. These animals may be resident in the area or migrating through the area (such as young salmon heading to sea). Areas where sensi-

tive creatures move through an area could lead to temporary closures to discharges. Sensitive life stages of animals ubiquitous in the area would not cause the same restrictions since the population is so large.

A particular concern of many people is the potential impact of ship wastewater discharge on humpback whales (*Megaptera novaeangliae*). The Panel reviewed available research and current knowledge with a view towards a particular area – Icy Strait – a water body frequented by humpback whales and cruise ships. This survey and discussion can be found in Appendix 9 of the Panel report to ADEC [1]. Current knowledge would seem to indicate that humpback whales are not affected by cruise ship wastewater if the ships follow the recommended discharge practice (discharge at minimum speed of 6 knots, 1 nautical mile from shore).

Oceanographic phenomena play a key role in moving water and thus moving the contaminants. In quiet fjords, large residence times due to small tidal exchange would need to be considered. A pollutant could potentially build up in the surface waters or when deeper waters are renewed infrequently.

Given these considerations, the Panel concluded:

1. Stationary discharge in a low tidal exchange area could lead to water quality issues and should be avoided.
2. The current requirements for large cruise ships – wastewater discharge at a minimum speed of 6 knots and at least 1 nautical mile from shore – are good management practices and should be practiced by all passenger ships.
3. No discharges (even for vessels with advanced treatment systems) should occur within 0.5 nautical mile of commercial bivalve shellfish beds.

The Panel offered two recommendations for identifying sensitive areas:

1. At this time, the Panel is not aware of any species that has both a sensitive life stage and a population that is limited to an area where cruise ships discharge wastewater. (Ubiquitous species are not considered for sensitive area delineation). However, should such a species be identified it could be an important issue for cruise ship discharge timing in a particular location.
2. Areas where long residence time or minimal neap tidal exchange occurs are areas where chemicals from wastewater discharges are a potential issue. Tidal exchange information could be used to prioritize areas for further study to determine whether or not wastewater discharge is a problem.

IX. Conclusion and Recommendations

Due to the high dilution rates of moving cruise ships there is little likelihood that treated or untreated passenger vessel wastewater discharges would result in contaminant impacts to marine life in the water column, at the sea surface, in subsurface sediments or on the shoreline. However, stationary discharge of untreated effluents in a low tidal exchange area could be cause for concern. The Panel did evaluate other sources and pathways (dry cleaning, photo labs, infirmaries, solid wastes, etc) by which traditional and non-traditional pollutants could reach the marine environment and found that the inspected vessels appear to have appropriate information, management and monitoring protocols [15]. It would also be worth further evaluating wastewater concentrations of materials other than the traditional EPA "priority pollutants", such as pharmaceuticals, hormones and fragrances [16, 17]. Environmental monitoring of contaminants in Alaska's inside passage waters would help assure that future vessel discharge activity will not become a problem. Finally, we suggest comparing biological injury caused by shear with the apparently low toxicity caused by pollutants.

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The recommendations in this report do not necessarily represent the official position of NOAA, EPA or the Government of the United States, nor does mention of trade names or commercial products constitute endorsement or recommendation for their use.

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